Cellular Product Technologies, LLC

Test Results
for
TTY/TDD
Over Live Digital Cellular Networks

July 21, 1998

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- Digital Cellular Network
  - IS-136 Time Division Multiple Access (TDMA)
  - Cellular One of San Luis Obispo (San Luis Obispo Cellular)
  - Roaming on ATT Wireless, site SB11O back-hauled to MTSO in Goleta.
    - Omni-directional Cell
    - Longitude 120° 26' 37" West
    - Latitude 34 ° 56' 36" North
  - Network supports ACELP Vocoder only

- Digital Cellular Phones[1]
  - Philips Consumer Communications - Aeon
  - NEC of America - Digital Talk 2000
  - Motorola - M70A

Notes:
1. It is not the goal of CTP to test the performance of the individual phones, therefore test data will refer to these phones as Phone "A", "B" and "C".

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- Tests Performed on IS-136 Digital Network
  - Stationary Test
    - Cellular Phone and TTY inside a parked car.
  - Drive Test[1]
    - Cellular Phone and TTY inside a car, driving on city streets (under 40 MPH).
  - Freeway Test[2]
    - Cellular Phone and TTY inside a car, driving on city streets and Freeway (including TDMA to AMPS handoff) of speeds up to 65 MPH.
  - Script Transmission Rate
    - Full Rate Test
      - 4164 Characters transmitted with no delays between characters
    - Half Rate Test
      - 4164 Characters transmitted with a 167mS delay between characters

Notes:

1. Due to safety concerns, Cellular Product Technologies does not recommend the use of a TTY while driving a motor vehicle.
2. These tests are not included in summary averages, as they were only performed to measure performance in unsuitable operating conditions.

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- TTY Over IS-136 Digital Cellular - Test Platform
  - Transmitting TTY
    - CPT Mobility™ TTY with DVC™ Technology (32K RAM Installed)
  - Receiving TTY
    - CPT Mobility™ TTY with DVC™ Technology (32K RAM Installed)
    - RS-232 Serial Port Installed
  - Software Version 1.4T (includes CTIA recommended test script)
  - Test Script Generation
    - Internal to Mobility™ TTY
  - Test Script Reception
    - P.C. Capture using XTALK via RS-232 Port on Mobility™ TTY
  - Scoring Method
    - SCORE.EXE Application developed by Lober & Walsh Engineering
      - UNIX and WIN32 Versions Available

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Land to Mobile Configuration

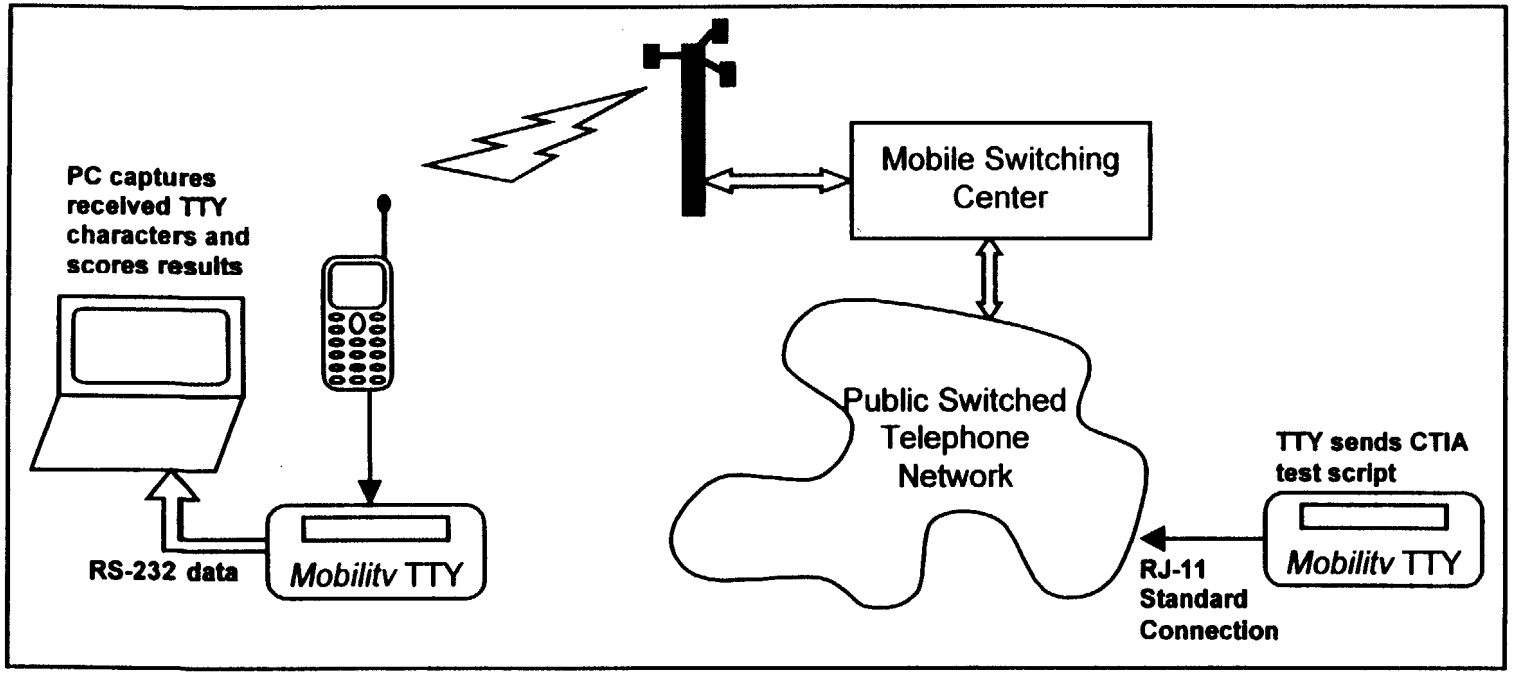

Illustration provided by Philips Consumer Communications

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Mobile to Land Configuration

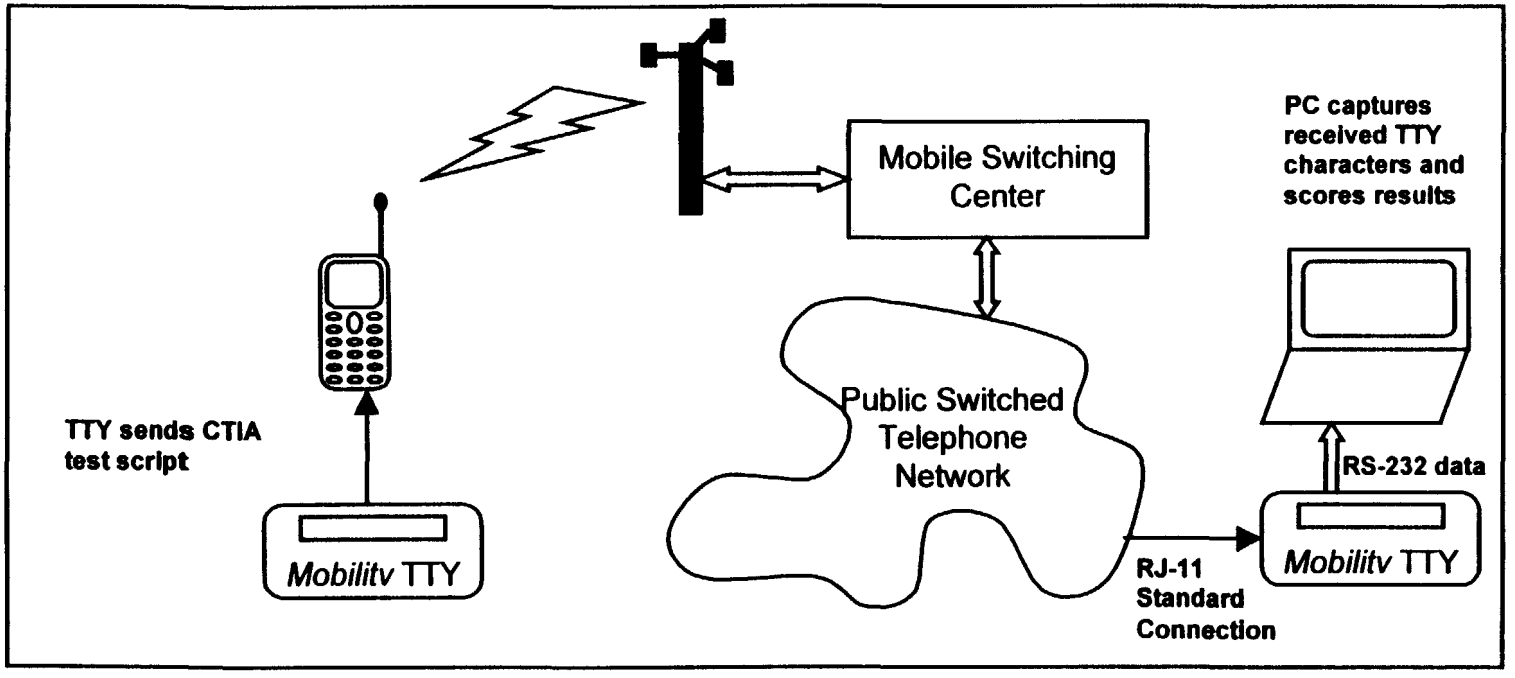

Illustration provided by Philips Consumer Communications

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Mobile to Mobile Configuration

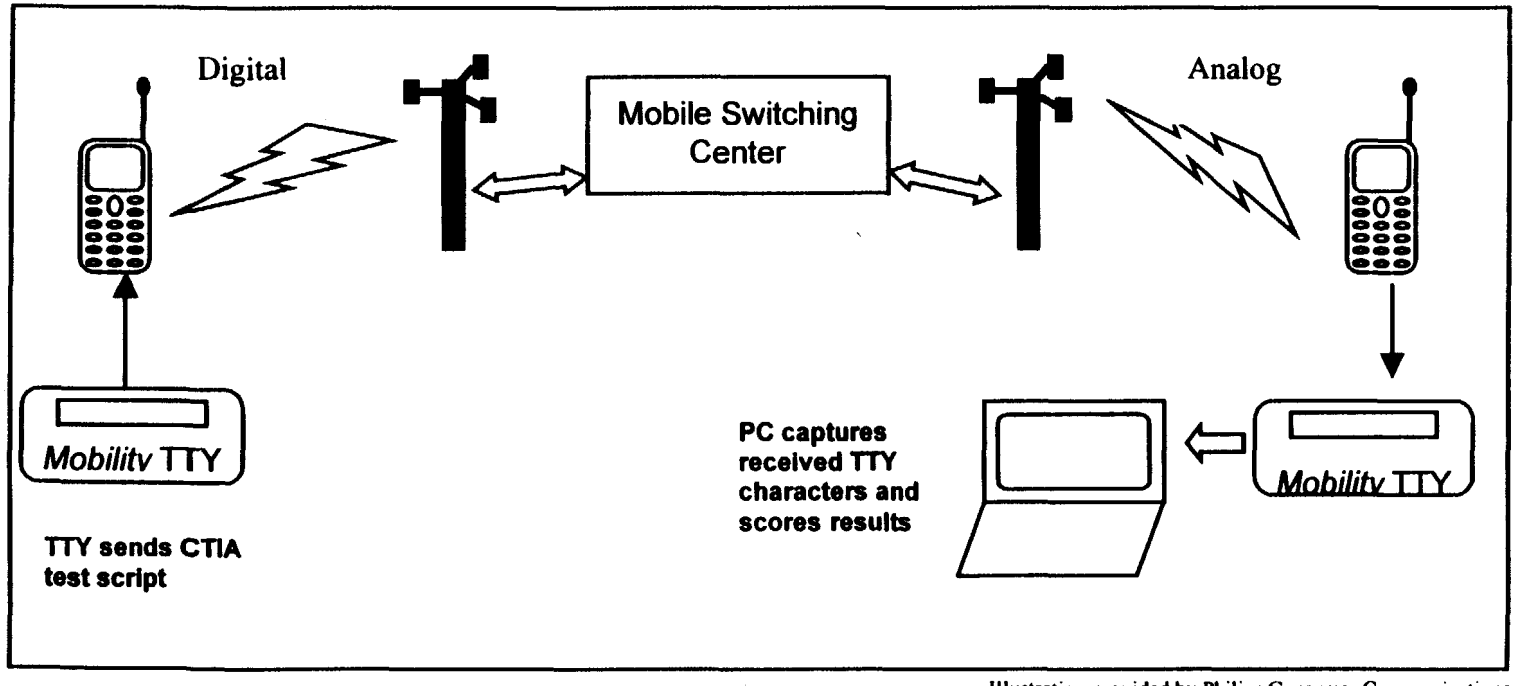

Illustration provided by Philips Consumer Communications

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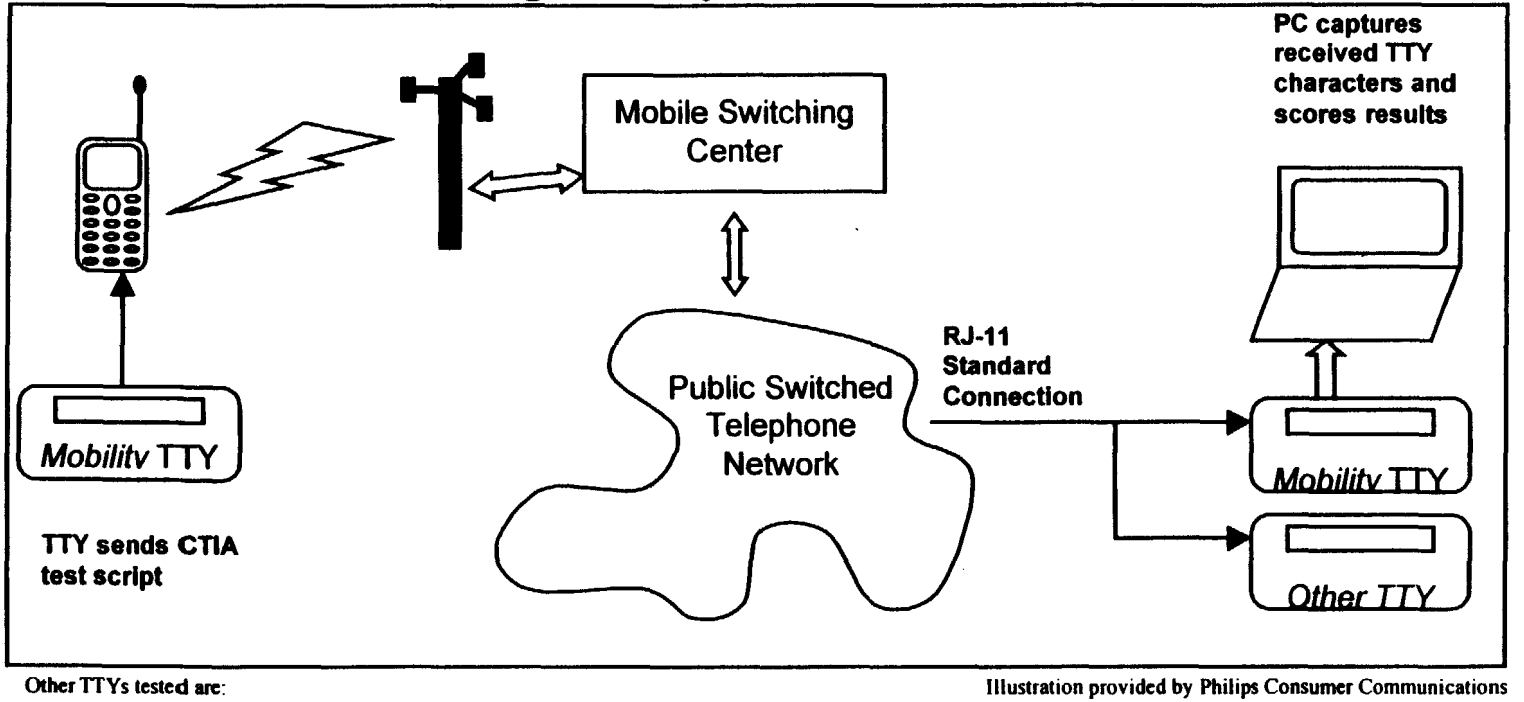
Small Sample Testing
(using Mobility™ TTY as a baseline)



Other TTYs tested are:
1 Ultratec Superprint
2. Ultratec Compact
3. Ultratec EZCom Pro
4. Ameriphone Dialogue IIP

Illustration provided by Philips Consumer Communications

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- Score Program
  - SCORE works by finding the best match between a transmitted script file and the received script file.
  - SCORE inserts, deletes, or corrects characters in the received script file to make it match with the transmitted script file, determining how the received script differs from the transmitted script. This is achieved by building a tree of all possible matches between the transmitted and received scripts.
  - Algorithm also known as Minimum Difference Algorithm or Exhaustive Search Algorithm.
  - Characters that were **inserted** are scored as a **missed** character.
  - Characters that were **deleted** are scored as an **added** character.
  - Characters that were **corrected** are scored as a **changed** character.
  - Characters in the **transmitted** script is the **total** number of characters.
  - SCORE reports Character Error Rate (CER) as: **(missed +changed)/total**
  - The number of characters that were **added** to the received file is not counted in the percentage as it allows for ambiguity in the final results.
  - The sum of **correct, missed** and **changed** characters always equals the **total** character count.

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- Score Example
  - Transmitted Script: The quick brown fox jumped over the lazy dogs.
  - Received Script: Te ui brow3fox jumped over the lazyFdogs.
  - Score: T#e #ui## brow##fox jumped over the lazy#dogs.
    - Character Error Rate = 14.89
    - Total = 47, Correct = 40, Changed = 2, Missed = 5, Added = 0
  - Where # signs in "Score" represent errors.
- Ambiguity of Added Characters in Score Results
  - Transmitted Script: ABCDE
  - Received Script: ACCDE
  - Score: A#CDE
  - Results
    - Score Method 1
      - SCORE **corrected** the "C" in position 2 to a "B".
      - Total = 5, Correct = 4, Changed = 1, Missed = 0, Added = 0
      - CER without **added** = 20%, CER with **added** = 20%
    - Score Method 2
      - SCORE **inserted** a "B" before the "C" in position 2, and the "C" in position 3 was **deleted**.
      - Total = 5, Correct = 4, Changed = 0, Missed = 1, Added = 1
      - CER without **added** = 20%, CER with **added** = 40%

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- IS-136 Conclusions
  - Good results were achieved independent of phone manufacturer.
  - Test results in terms of CER vary depending on the quality of the "land side" and "mobile side" TTY's FSK receiver. Cellular Product Technologies Mobility™ TTYs[1] were used for all "full length" tests.
  - Reliable conversation[2] from a stationary location with good signal strength[3] is achieved on an IS-136 Digital Traffic Channel.
    - **Half Rate - average CER of 0.88%.**
    - **Full Rate - average CER of 2.84%.**
  - Reliable conversation from a moving vehicle[4] with good signal strength is also achieved on an IS-136 Digital Traffic Channel.
    - **Half Rate - average CER of 1.70%.**
    - **Full Rate - average CER of 3.31%.**
  - Introducing inter-character delays reduces character errors:
    - **Stationary Test CER improvement 1.96%**
    - **Drive Test CER improvement 1.61%**

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- IS-136 Conclusions (continued)
  - Small sample[5] testing was performed using the following "land side" TTYs. A Mobility™ TTY was used in parallel to baseline the test:
    - Test 1
      - Mobility™ TTY: CER: 01.18%, Total: 510, Correct: 504, Changed: 05, Missed: 01, Added: 00
      - Ultratec Compact[A]: CER: 18.04%, Total: 510, Correct: 418, Changed: 46, Missed: 46, Added: 05
    - Test 2
      - Mobility™ TTY: CER: 00.39%, Total: 510, Correct: 508, Changed: 02, Missed: 00, Added: 03
      - Ultratec EZCom Pro[B]: CER: 23.14%, Total: 510, Correct: 392, Changed: 55, Missed: 63, Added: 05
    - Test 3
      - Mobility™ TTY: CER: 00.78%, Total: 510, Correct: 506, Changed: 03, Missed: 01, Added: 00
      - Ultratec Superprint[C]: CER: 08.24%, Total: 510, Correct: 468, Changed: 19, Missed: 23, Added: 00
    - Test 4
      - Mobility™ TTY: CER: 00.00%, Total: 510, Correct: 510, Changed: 00, Missed: 00, Added: 00
      - Ameriphone Dialogue[D]:CER: 02.35%, Total: 510, Correct: 498, Changed: 07, Missed: 05, Added: 01

Notes:
A. Compact has no Serial Number visible, and is an acoustic coupled device.
B. EZCom Pro Serial Number 7310002270 is a direct connect device.
C. Superprint 4420 Serial Number 58636 was used in direct connect configuration.
D. Dualogue IIP Serial Number 17127 was used in direct connect configuration.

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- IS-136 Conclusions (continued)
  - FACCH[6] messages result as additional character errors.
  - High Character Error Rates result from "low quality" cellular connection.
  - **Because of the variance in quality of TTYs in the field today, it is not possible to ensure acceptable Character Error Rates without replacing or "enhancing" the existing TTYs. CPT is currently designing a "retrofit module", designed to give existing TTYs the same performance as the Mobility™ TTY.**

Notes:
1. The Mobility™ TTY FSK receiver has a dynamic range greater than 49dB.
2. The term "reliable conversation" is used as a subjective measure of quality, and does not relate to any definition of quality issued by the CTIA/PCIA TTY Forum.
3. Signal Strength deemed "good" ranged from -65dBm to -80dBm.
4. Due to safety concerns, Cellular Product Technologies does not recommend the use of a TTY while driving a motor vehicle.
5. Samples of 510 characters were received by these devices, the printouts or displayed characters were transposed and scored using the Score Application.
6. FACCH (Fast Associated Control Channel) messages include; mobile power level change, handoff, MAHO RSSI request, timing adjustments.

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Field Test Results

Page 1

Test Date	Time	Direction	TX Rate	Test Type	Format	Vocoder	Phone	CER	Total	Correct	Changed	Missing	Added
July 7, 1998	5:53 PM	Mobile to Land	Full Rate	Stationary	AMPS	N.A.	Phone "A"	0.00%	4164	4164	0	0	3
July 8, 1998	12:44 PM	Mobile to Land	Full Rate	Stationary	IS-136	ACELP	Phone "A"	5.00%	4164	3956	116	92	91
July 8, 1998	1:10 PM	Mobile to Land	Full Rate	Stationary	IS-136	ACELP	Phone "A"	2.28%	4164	4069	60	35	25
July 8, 1998	1:37 PM	Mobile to Land	Full Rate	Stationary	IS-136	ACELP	Phone "B"	2.86%	4164	4045	80	39	17
July 8, 1998	1:50 PM	Mobile to Land	Full Rate	Stationary	IS-136	ACELP	Phone "B"	2.07%	4164	4078	57	29	10
July 8, 1998	2:12 PM	Mobile to Land	Full Rate	Stationary	IS-136	ACELP	Phone "A"	1.90%	4164	4085	55	24	17
July 8, 1998	4:11 PM	Mobile to Land	Full Rate	Driving	IS-136	ACELP	Phone "A"	2.47%	4164	4061	46	57	46
July 8, 1998	4:44 PM	Mobile to Land	Full Rate	Driving	IS-136	ACELP	Phone "B"	2.76%	4164	4049	85	30	14
July 8, 1998	5:05 PM	Mobile to Land	Full Rate	Driving	IS-136	ACELP	Phone "A"	3.41%	4164	4022	57	85	82
July 8, 1998	5:33 PM	Mobile to Land	Full Rate	Driving	IS-136	ACELP	Phone "B"	4.61%	4164	3972	92	100	84
July 9, 1998	2:55 PM	Mobile to Land	Half Rate	Stationary	IS-136	ACELP	Phone "A"	1.03%	4164	4121	34	9	3
July 9, 1998	3:48 PM	Mobile to Land	Half Rate	Stationary	IS-136	ACELP	Phone "B"	0.96%	4164	4124	34	6	2
July 9, 1998	4:20 PM	Mobile to Land	Half Rate	Stationary	IS-136	ACELP	Phone "B"	1.75%	4164	4091	55	18	3
July 9, 1998	5:00 PM	Mobile to Land	Half Rate	Stationary	IS-136	ACELP	Phone "A"	0.77%	4164	4132	27	5	1
July 9, 1998	5:45 PM	Mobile to Land	Half Rate	Driving	IS-136	ACELP	Phone "A"	1.32%	4164	4109	45	10	3
July 9, 1998	6:15 PM	Mobile to Land	Half Rate	Driving	IS-136	ACELP	Phone "B"	3.53%	4164	4017	131	16	8
July 13, 1998	11:42 PM	Mobile to Land	Half Rate	Driving	IS-136	ACELP	Phone "B"	1.68%	4164	4094	61	9	1
July 13, 1998	12:15 PM	Mobile to Land	Half Rate	Driving	IS-136	ACELP	Phone "B"	1.54%	4164	4100	43	21	1
July 13, 1998	1:00 PM	Mobile to Land	Full Rate	Stationary	IS-136	ACELP	Phone "A"	3.05%	4164	4037	121	6	2
July 13, 1998	1:30 PM	Mobile to Land	Full Rate	Stationary	IS-136	ACELP	Phone "B"	4.42%	4164	3980	82	102	86
July 13, 1998	2:30 PM	Mobile to Land	Half Rate	Driving	IS-136	ACELP	Phone "A"	0.96%	4164	4124	37	3	2
July 13, 1998	3:15 PM	Mobile to Land	Half Rate	Driving	IS-136	ACELP	Phone "A"	0.84%	4164	4129	26	9	3
July 13, 1998	3:45 PM	Mobile to Land	Half Rate	Driving	IS-136	ACELP	Phone "B"	1.97%	4164	4082	62	20	1
July 13, 1998	4:30 PM	Mobile to Land	Half Rate	Freeway	IS-136	ACELP	Phone "A"	3.17%	4164	4032	49	83	4

All Scripts are available for viewing at: http://www.cellulartty.com/Products/Data/16.html

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Field Test Results

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Test Date	Time	Direction	TX Rate	Test Type	Format	Vocoder	Phone	CER	Total	Correct	Changed	Missing	Added
July 15, 1998	3:49 PM	Land to Mobile	Half Rate	Stationary	IS-136	ACELP	Phone "B"	5.16%	4164	3949	177	38	4
July 15, 1998	4:25 PM	Land to Mobile	Half Rate	Stationary	IS-136	ACELP	Phone "A"	1.10%	4164	4118	33	13	1
July 15, 1998	5:12 PM	Land to Mobile	Half Rate	Driving	IS-136	ACELP	Phone "A"	2.11%	4164	4076	63	25	8
July 15, 1998	5:49 PM	Land to Mobile	Half Rate	Driving	IS-136	ACELP	Phone "B"	1.39%	4164	4106	38	20	2
July 16, 1998	2:30 PM	Mobile to Land	Half Rate	Stationary	IS-136	ACELP	Phone "C"	0.24%	4164	4154	6	4	0
July 16, 1998	3:30 PM	Mobile to Land	Half Rate	Stationary	IS-136	ACELP	Phone "C"	0.29%	4164	4152	7	5	1
July 16, 1998	4:15 PM	Mobile to Land	Full Rate	Stationary	IS-136	ACELP	Phone "C"	1.10%	4164	4118	38	8	4
July 16, 1998	4:45 PM	Mobile to Land	Full Rate	Stationary	IS-136	ACELP	Phone "C"	0.22%	4164	4155	6	3	0
July 16, 1998	5:15 PM	Mobile to Land	Half Rate	Driving	IS-136	ACELP	Phone "C"	0.67%	4164	4136	23	5	0
July 16, 1998	6:00 PM	Mobile to Land	Half Rate	Driving	IS-136	ACELP	Phone "C"	0.17%	4164	4157	5	2	0
July 16, 1998	7:00 PM	Mobile to Land	Half Rate	Freeway	IS-136	ACELP	Phone "C"	3.39%	4164	4023	47	94	12
July 17, 1998	1:00 PM	Mobile to Mobile	Half Rate	Stationary	IS-136	ACELP	"A" & "C"	0.50%	4164	4143	17	4	3

All Scripts are available for viewing at: http://www.cellulartty.com/Products/Data/16.html

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Field Test Results

Page 3

(Small Sample Tests)

Test Date	Time	Direction	TX Rate	TTY	Format	Vocoder	Phone	CER	Total	Correct	Changed	Missing	Added
July 17, 1998	11:20 AM	Mobile to Land	Half Rate	Mobility	IS-136	ACELP	Phone "C"	1.18%	510	504	5	1	0
July 17, 1998	11:30 AM	Mobile to Land	Half Rate	Mobility	IS-136	ACELP	Phone "C"	0.39%	510	508	2	0	3
July 17, 1998	11:40 AM	Mobile to Land	Half Rate	Mobility	IS-136	ACELP	Phone "C"	0.00%	510	510	0	0	0
July 17, 1998	11:50 AM	Mobile to Land	Half Rate	Mobility	IS-136	ACELP	Phone "C"	0.78%	510	506	3	1	0

All Scripts are available for viewing at: http://www.cellulartty.com/Products/Data/16.html

Note:
The Mobility TTY was used as a baseline to ensure the cellular channel was of reasonable quality.

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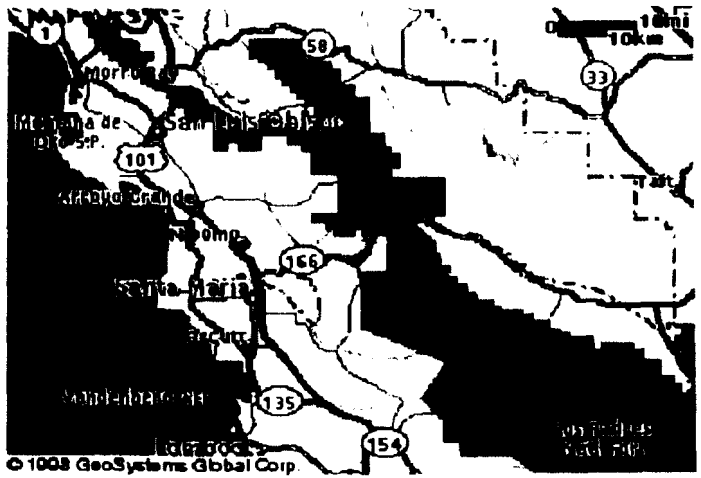
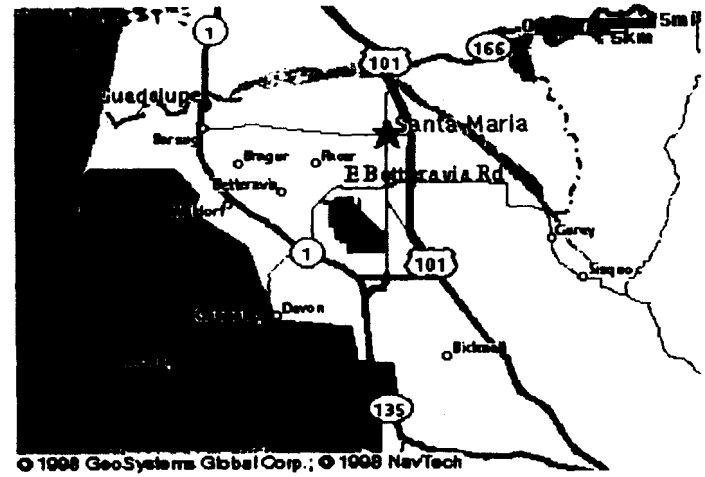
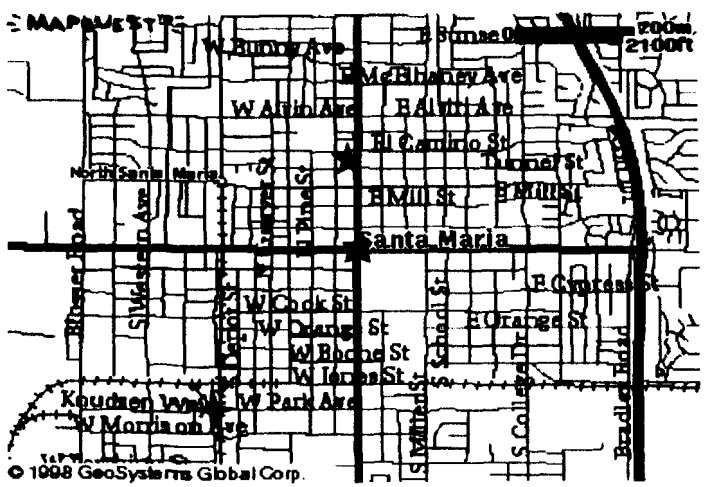
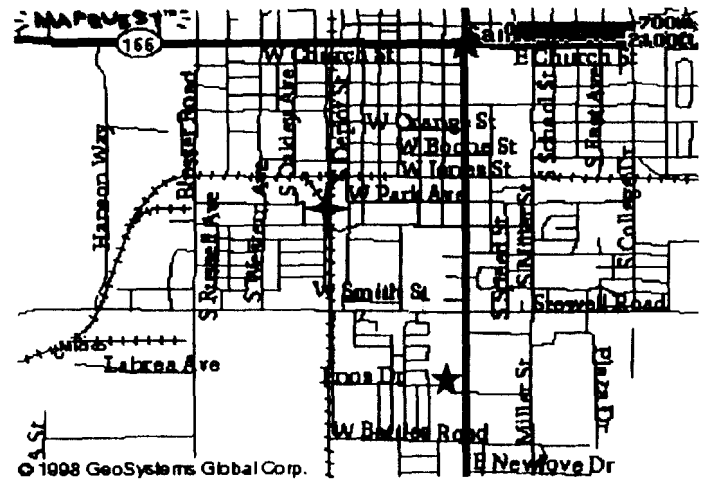






Stationary Test Location



Drive Test Location

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- Background on DVC™ Technology
  - CPT developed Digital Vocoder Compensating Technology (DVC™) to successfully pass FSK audio (used in TTY communications) over a digital cellular network.
  - DVC™ Compensation does not modify in any way the BAUDOT character set.
  - Voice Coders and Decoders (vocoders) used in IS-136 Digital Cellular Networks include IS-54 (VSELP), and IS-641 (ACELP).
  - Currently, most IS-136 systems in the U.S. only support ACELP vocoders.
  - Vocoders effect the FSK audio by "distorting" the FSK waveform.
  - The time domain is effected by adding "Pops" in amplitude thereby increasing the dynamic range of the FSK waveform.[1]
  - The frequency domain is not effected greatly, as no destructive harmonic byproducts are generated by the vocoder.[2]

Notes:
1. See Plots 1 and 3.
2. See Plots 2 and 4.

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- Background on DVC™ Technology (continued)
  - The key to successful TTY communication over an IS-136 TDMA network, is the FSK receiver in the TTY.
    - Unfortunately, there is no standard for the performance of a TTY receiver.
    - The TTYs currently in homes, offices and emergency facilities have FSK receivers varying in performance.
  - Since TTY Devices with varying grades of FSK receivers are used throughout the world, it is important to compensate as much as possible (on the transmit side) to make-up for the shortcomings in the receivers of those TTYs.
  - How CPT resolves the "Vocoder Problem".
    - Transmit Side
      - DVC™ signal processing techniques applied to the transmitted FSK audio help the FSK tones pass through the vocoder.
      - Introducing inter-character delays to decreases the CER.
    - Receive Side
      - The Mobility™ TTY has a high quality FSK receiver with a dynamic range greater than 49dB.

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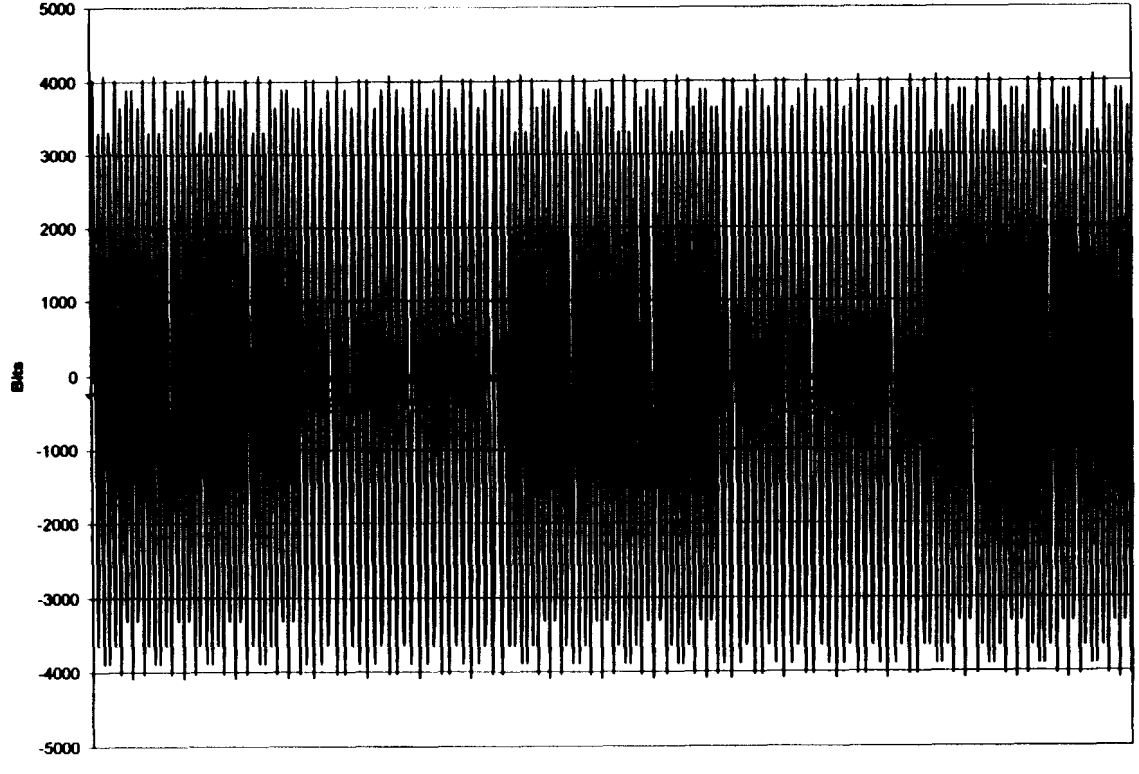
Plot #1

Time Domain Plot - 100mS in duration consisting of five 20mS periods, Frequency Shifting (non-coherent FSK modulation) between 1400 Hertz and 1800 Hertz. This plot is a baseline for how FSK tones look "normally".



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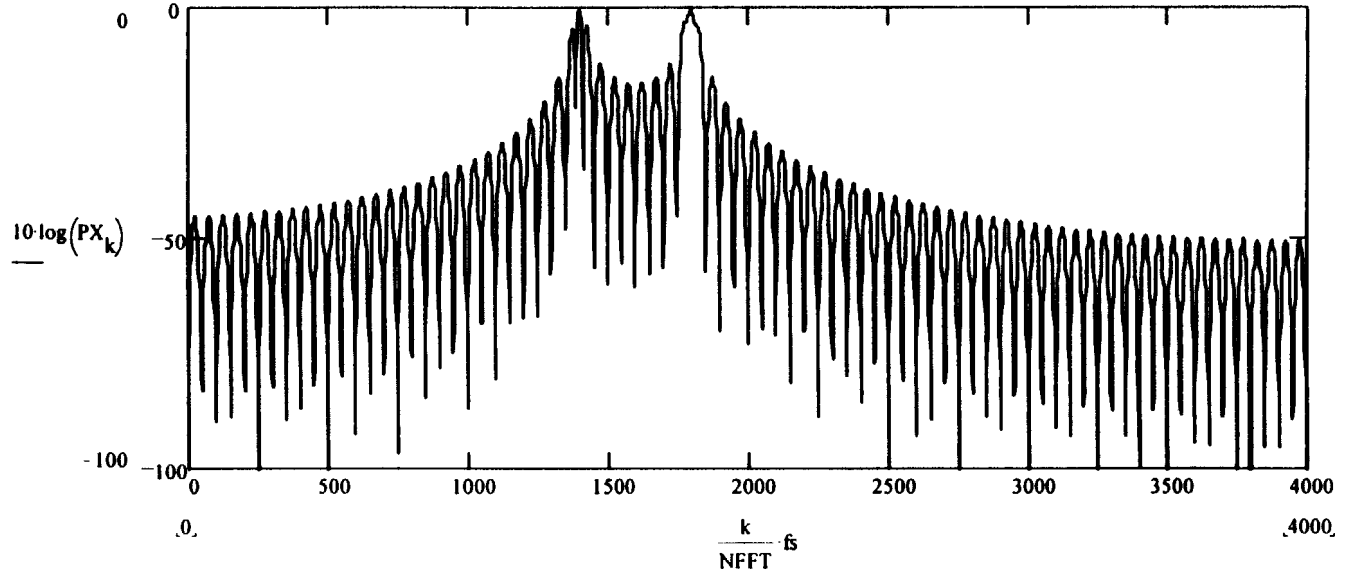
Plot #2

Frequency Domain Plot - 800 samples at a rate of 8KHz (100mS), consisting of five 20mS periods, Frequency Shifting (non-coherent FSK modulation) between 1400 Hertz and 1800 Hertz. This plot is a baseline for how the frequency domain looks "normally".



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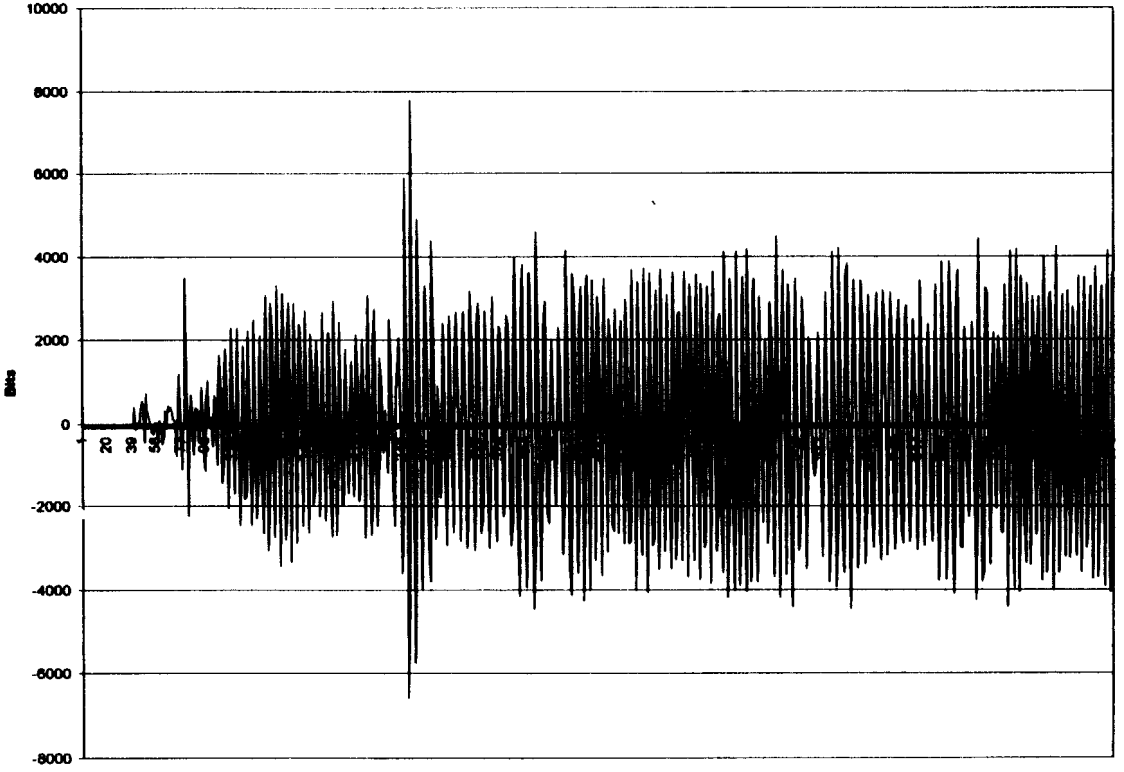
Plot #3

Time domain plot, 100mS in duration consisting of five 20mS periods, Frequency Shifting (non-coherent FSK modulation) between 1400 Hertz and 1800 Hertz. This plot has the ACELP vocoder engaged, and shows the "pops" added. There is an increase in dynamic range, but the tones are still discernable.



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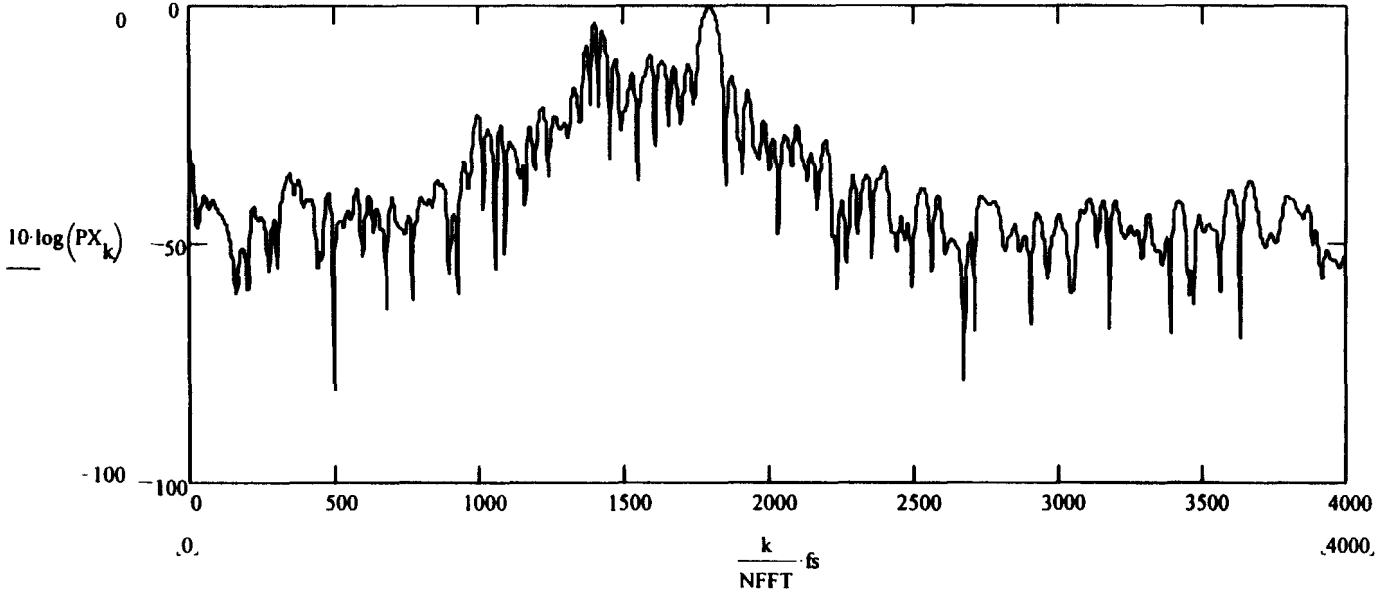
Plot #4

Frequency Domain Plot – 800 samples at a rate of 8KHz (100mS), consisting of five 20mS periods, Frequency Shifting (non-coherent FSK modulation) between 1400 Hertz and 1800 Hertz. This plot has the ACELP vocoder engaged. The purpose of this plot is to show the frequency spectrum is only minimally corrupted by the vocoder.



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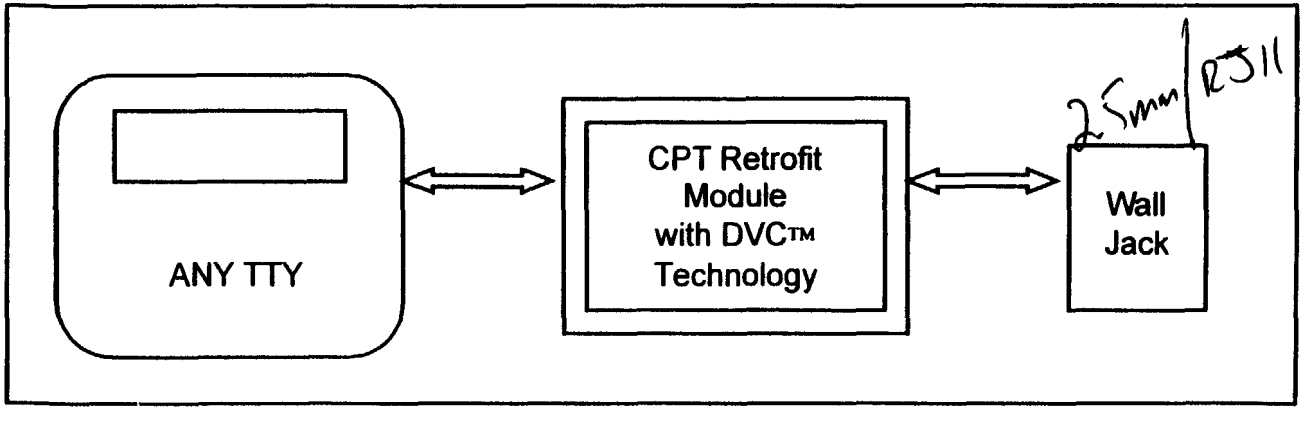
- Products for existing TTYs
  - CPT is developing a "retrofit module" for use with existing TTYs. The "retrofit module" will be installed between the TTY and the wall jack, and will contain:
    - Transmit Side
      - Receive FSK tones from the local TTY.
      - Interpret and re-generate the TTY tones applying DVC™ technology.
    - Receive Side
      - Incorporate a high quality FSK receiver with a dynamic range greater than 49dB.
      - Receive FSK tones from the remote TTY
      - Re-generate the tones, and send to the local TTY.



Cellular Product Technologies, LLC

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